

AD-A021 076

FEASIBILITY OF USE OF PLASTIC FOAMS FOR SMALL VESSEL  
FLOTATION DEVICES

S. M. Sun, et al

Monsanto Research Corporation

Prepared for:

Coast Guard

January 1976

DISTRIBUTED BY:

**NTIS**

National Technical Information Service  
U. S. DEPARTMENT OF COMMERCE

ES2173

Report No. CP-9-21-76

ADA021076

# FEASIBILITY OF USE OF PLASTIC FOAMS FOR SMALL VESSEL FLotation DEVICES

S. H. SUN

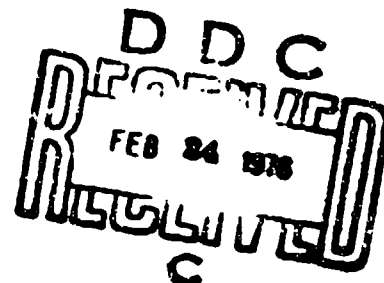
J. L. SCHREIBER

I. O. SALVER



FINAL REPORT

JANUARY 1976



Document is available to the public through the  
National Technical Information Service,  
Springfield, Virginia 22161

Prepared for

DEPARTMENT OF TRANSPORTATION  
UNITED STATES COAST GUARD  
Office of Research and Development  
Washington, D.C. 20540

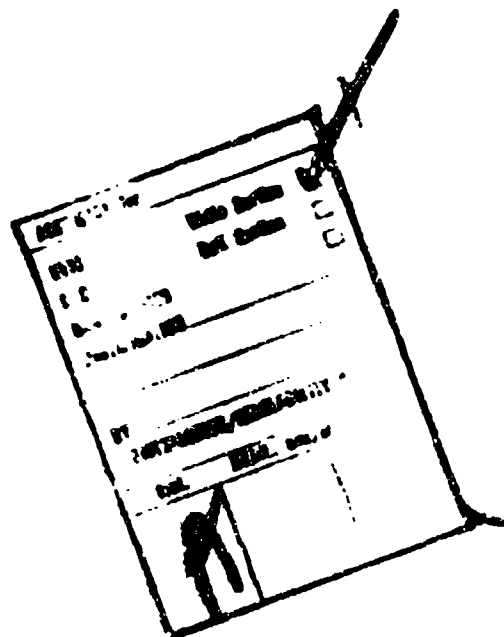
Reproduced by  
NATIONAL TECHNICAL  
INFORMATION SERVICE  
U.S. Department of Commerce  
Springfield, VA. 22151

The work reported herein was accomplished for the U. S. Coast Guard's Office of Research and Development, Marine Safety Technology Division, as part of its program in Commercial Vessel Safety.

The contents of this report reflect the views of S. H. Sun, J. I. Rosenbaum, and L. O. Sniyer, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policy of the Coast Guard. This report does not constitute a standard, specification, or regulation.



W. V. Smith, Jr.  
Captain, U. S. Coast Guard  
Chief, Marine Safety Technology  
Division  
Office of Research and Development  
U. S. Coast Guard Headquarters  
Washington, D. C. 20390



1. Report No. <b>CG-D-21-76</b>	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle <b>Feasibility of Use of Plastic Foams for Small Vessel Flotation Devices</b>		5. Report Date <b>January 1976</b>
		6. Performing Organization Code
7. Author(s) <b>S. M. Sun, J. L. Schwandeman, and I. O. Salyer</b>		8. Performing Organization Report No. <b>MRC-DA-518</b>
9. Performing Organization Name and Address <b>Monsanto Research Corporation Dayton Laboratory Dayton, Ohio 45407</b>		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. <b>DOT-CG-52,454-A</b>
12. Sponsoring Agency Name and Address <b>U. S. Coast Guard (G-DST-2) 400 7th Street, S. W. Washington, D. C. 20590</b>		13. Type of Report and Period Covered <b>Final Report</b>
		14. Sponsoring Agency Code <b>G-DST-2</b>
15. Supplementary Notes <b>The U. S. Coast Guard Research and Development's technical representative for the work described in this report was Jonathon R. Amy.</b>		
16. Abstract <p>This report describes work performed to demonstrate the feasibility of using instantly deployable plastic foams to provide flotation for small vessels which are in a sinking condition. The ability to generate foams under fifteen feet of water was demonstrated. These foams provided sixty-one pounds of flotation/cubic foot of foam as originally generated. After twenty-four hours immersion under fifteen feet of water, the foams still provided fifty pounds of flotation per cubic foot. Non-burning solvent/pneumatogen systems were developed for the foams. The use of additives in the foam made it fire retardant. The capability to generate foams down to -10°C (14°F) was demonstrated. Below that temperature, the foam solution becomes too viscous to flow from the storage cylinder. Long-term storage tests are in progress.</p>		
17. Key Words <b>Flotation Underwater Foams Flotation Devices Small Vessels Foams Instant Foam</b>		18. Distribution Statement <b>This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.</b> <b>PRICES SUBJECT TO CHANGE</b>
19. Security Classif. (of this report) <b>Unclassified</b>	20. Security Classif. (of this page) <b>Unclassified</b>	21. No. of Pages <b>75</b>
		22. Price <b>4.00 - 2.25</b>

## FOREWORD

This is the final report on contract DOT-CG-52454-A, a 4 month program to demonstrate the feasibility of using instantly deployable foams to provide flotation to small vessels which are in imminent danger of sinking.

We would like to thank the Coast Guard for the opportunity to work on this interesting and worthwhile project. We would particularly like to thank Commander Bachtell and Mr. John Amy for their help and interest in this program. We gratefully acknowledge the capable assistance of Mr. Norval Jones of Monsanto Research Corporation in the execution of this program.

## TABLE OF CONTENTS

	<u>Page</u>
1. INTRODUCTION	1
2. PROGRAM SUMMARY	2
3. TECHNICAL DISCUSSION	3
3.1 INSTANT FOAM SYSTEM	3
3.2 EVALUATION OF POLYMERS	5
3.3 LOW TEMPERATURE OPERATION	7
3.3.1 Evaluation of High Pressure Gases as Solvent/Pneumatogen	7
3.3.2 Cooled Foam Solution Over-pressured by an Inert Gas (Nitrogen)	11
3.3.3 Specially Prepared Polystyrene/ Methyl Chloride/Freon 13B1 Foam	11
3.3.4 Characteristics of "Instant" Type Foam Solutions at Low Temperatures	13
3.4 REDUCTION OF FLAMMABILITY	14
3.4.1 Burning Characteristics of Polystyrene Foam	14
3.4.2 Flammability of Solvent/Pneumatogen	19
3.4.3 Safety of Foam System in Fire Situation	21
3.5 FOAM GENERATION UNDER 15 FEET OF WATER	22
3.5.1 Test Facility for Foam Generation Under 15 Feet of Water	22
3.5.2 Test Procedure	24
3.6 WATER ABSORPTION OF POLYSTYRENE FOAM WHEN IMMERSED IN 15 FEET OF WATER	24
3.6.1 Evaluation of Waterproofing Agents	28
3.6.2 Effect of Cell Size	28
3.6.3 Quantitative Water Absorption Under 15 Feet of Water	
3.7 SHELF LIFE	31
3.7.1 Short-Term Storage at Different Temperatures	31
3.7.2 Long-Term Storage at 70-75°F (21-24°C)	31

## TABLE OF CONTENTS

	<u>Page</u>
4. CONCLUSIONS	33
5. RECOMMENDATIONS FOR FUTURE WORK	34
5.1 REDUCTION OF WATER ABSORPTION	34
5.2 LOW TEMPERATURE OPERATION	34
5.3 DEVELOPMENT OF PROTOTYPE EQUIPMENT	35
6. REFERENCES	36
APPENDIX	37

## LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1.	Set-up for Foam Discharge Under 18 Inches Water	6
2.	Instant Foam Cylinder with Necessary Valving for Over-pressuring with Nitrogen	12
3.	Gas Forcing Its Way Through the Foam Solution	15
4.	Use of a Diaphragm to Insure Flow of Very Viscous Foam Solution	16
5.	Set-up for Foam Generation Under 15 Feet of Water	23
6.	Assembled Foam Test Stand	25
7.	Foam Generated Under Water Viewed Through Tank Viewing Port.	26



## LIST OF TABLES

<u>Table</u>		<u>Page</u>
1	Vapor Pressure of Eight Compresses Gases at Different Temperatures (lb/in. <sup>2</sup> absolute)	8
2	Foam Formulation Tested at Low Temperature (% Composition)	10
3	Combustion Test Results of Fire Retarded Polystyrene Instant Foam	18
4	Burning Characteristics of Liquefied Gases of Potential Interest in Instant Foam	20
5	Burning Characteristics of Gas Mixtures	21
6	Test Results of Polystyrene Instant Foam Generation Under 15 Feet of Water	27
7	Water Absorption by Foam Immersed Under 15 Feet of Water and Net Buoyancy	29

## 1. INTRODUCTION

The feasibility of using so-called "instant foams" was investigated as an approach to providing emergency flotation for damaged small vessels. These foams are made from a solution of a high molecular weight polymer in a liquefied gas. These polymer solutions exist as highly viscous solutions or swollen gels. They can be stored in pressure containers for long periods of time and exist as gels as long as the container is kept closed.

When the container is opened, the solution of polymer in liquefied gas is exposed to atmospheric pressure and the solvent evaporates to a gas. In evaporating, the gas forms bubbles in the polymer solution and a foam is formed instantly.

This feasibility study had four principal objectives, each of which comprised a task to be completed.

- . Operation at  $-22^{\circ}\text{F}$  ( $-30^{\circ}\text{C}$ )
- . Adequate storage life (18-month target)
- . Low flammability, to reduce the hazards from fire for all components in the foam system.
- . Generation of foam under 15 feet of water.

The overall feasibility of a foam flotation system was demonstrated.

Work on this program was initiated on 15 June, 1975 and experimental work on the project was completed on 12 September, 1975, except for long-term storage tests, which are scheduled for completion on 16 March, 1977.

## 2. PROGRAM SUMMARY

This program demonstrated the overall feasibility of using foams formed from solutions of polymers in liquefied gases for the emergency flotation of small vessels. The precursor foam solutions must be stored in pressure containers capable of holding 60 psig pressure at 75°F. As long as pressure is maintained on the solution, no foaming results. When the solution container valve is opened, foam forms immediately by solvent evaporation.

It was demonstrated that 1.5 to 2 lb/cu ft foams could be deployed rapidly under a 15-foot head of water. There was no detectable difference in the manner in which the foam formed under water compared to its formation in air. However, foams generated under water and left immersed at that depth for 24 hours absorbed water and some buoyancy was lost. Water repellants were not effective in preventing this water absorption. Fine-celled foams absorbed less water than did large-cell foams, and there was evidence that water absorption was by diffusion through the foam cell walls.

The total loss of flotation after 24 hours of immersion at 15 ft was 20% of the original buoyancy. Thus, 1.5 lb/cu ft small-cell foam that furnished 61 pounds of flotation per cu ft initially, would still furnish 50 to 51 pounds of flotation after 24 hours immersion.

Non-burning polystyrene foam formulations were developed that contained methyl chloride and Freon 13B1 (bromotrifluoromethane) as the solvent/pneumatogen. This gas combination was not ignited by a propane torch flame. The polymer foam itself was rendered non-burning by the addition of 2% by weight (of the polymer) of a Monsanto Company proprietary flame retardant agent.

Operation of the foam system containing a mixed solvent/pneumatogen (methyl chloride and Freon 13B1) was demonstrated down to 14°F (-10°C). Foams in the 3 to 6 lb/cu ft range were made made at this temperature. It was not possible, however, to generate these foams at 5°F (-15°C) because the solution become so viscous that they could not be made to move out of the cylinder. This work showed that the viscosity increase at lower temperatures is probably the controlling factor in limiting low-temperature performance.

Short-term storage stability (20 days at 75°F and 120°F) was demonstrated. Long-term storage stability tests (18 months) were initiated.

### 3. TECHNICAL DISCUSSION

#### 3.1 INSTANT FOAM SYSTEM

Monsanto Research Corporation (MRC) has developed a system which produces a polymeric foam instantly on demand. In this system, a polymer is dissolved in a liquefied gas, which acts as both the solvent for the polymer and the pneumatogen (blowing agent) for the foam. Normally, a secondary solvent is included in the formulation to modify the foam properties.

The instant foams were originally developed by MRC under contract with the U. S. Navy to provide a rapid and positive means of inflating a PK-2 life raft (U. S. Naval Weapons Laboratory, contract N178-8823, N00178-67-C-0246, and N00178-68-C-0301). A further objective of these programs were to provide a life raft which would not lose its buoyancy after puncture by small arms fire.

These foams were further developed during a contract with the U. S. Army to provide a flotation system for individuals wearing body armor (U. S. Army Natick Laboratories, contract DAAG17-69-C-0107).

More recently, work was done on these foams to provide the Army with an energy absorbing foam for air-dropped loads (U. S. Army contract DAAK03-74-C-0080).

The instant foam solutions provide a basically simple system of producing foams since they require neither mixing of two or more components nor a chemical reaction at the time of use, as is necessary when polyurethane foams are made. Their foaming capability depends on a change of state, namely, the boiling of the liquefied gas solvent when the pressure is lowered. The expanding vapor produces the foam from the viscous polymer solution.

These foam systems, depending as they do on a liquefied gas, must be kept under pressure (60-75 psi). As such, they must be kept in closed pressure vessels. As long as the pressure is maintained, the solution does not foam. Exposing the solution to lower pressure, either by opening a valve on the pressure bottle or by rupturing either the container or a sealing disc, causes the solvent to boil and a foam forms immediately. The foam is fully formed as it leaves the pressure tank and can be handled at once. There is a gradual increase in strength and stiffness of the foam during the first 10 to 15 minutes after formation. This is due to solvent loss immediately after formation.

The speed of foam formation can be very rapid. For example, if a one-gallon container (6 inch outside diameter) of foam solution has its end blown off explosively, the entire contents of the tank foams in 50 milliseconds. In contrast, if the same size tank is emptied through a one inch ball valve, the time to discharge the foam is 15 seconds. The rate of discharge and foam formation is dependent on the geometry and size of the opening through which the solution leaves its storage tank.

These foams are not tacky as formed and do not adhere to their surroundings. This is an advantage in the present application as removal of foam and clean up would be facilitated.

In the earliest work done on this system, 500 ml glass pressure bottles were used as the foam solution containers. Normally, the foam composition is brought into solution or homogenized by attaching the charged containers to a wheel and tumbling them intermittently for at least 16 hours.

In work prior to the present program, the instant foam system had been scaled up to 800-ml steel cylinders, one-gallon cylinders, five-gallon tanks, and 108-gallon tanks. Polymer foam is generated instantly when these containers are opened, either manually or explosively. In earlier work, as well as in this program, the performance of polystyrene and polyvinyl acetate instant foams was extensively studied.

Prior to this program on small vessel flotation, polystyrene had been established as the major polymer component of the instant foam system. Dimethyl ether was used as the solvent/pneumatogen in the earliest formulas. Later it was replaced with methyl chloride. This liquefied gas is considerably less flammable than dimethyl ether. The standard formulation for polystyrene foam at the beginning of this program was as follows:

<u>Material</u>	<u>Percent (by wt)</u>
Polystyrene (Lustrex HH-101)	62.30
Glass microballoons (Emerson Cummings 1G101)	1.19
Freon-11	3.97
Methyl chloride	27.78
Triton X-200 (Rohm and Haas)	<u>4.76</u>
Total	100.00

The glass microballoons are used as a nucleating agent to initiate the formation of foam bubbles so as to render the cell size more uniform. Freon-11 serves as a secondary solvent and assists in stabilizing the foam. Triton X-200 is a surfactant that aids in nucleating and forming bubbles. It also serves as a lubricant to help the foam solution to flow smoothly from the container when discharged. Triton X-200 contains water, which may react with methyl chloride and generate hydrogen chloride which can be corrosive to the metal cylinders. In this study, Igepal CO-970, a surfactant not containing water, was used instead of Triton X-200.

Polyvinyl acetate instant foam has also been studied. A number of formulations using polyvinyl acetate have been evaluated. High quality foam is produced with the following composition:

<u>Material</u>	<u>Percent (by wt)</u>
Vinac B-7	54.68
Glass microballoons	0.83
Freon-11	13.72
Freon-12	23.91
Triton X-200	6.86
Total	100.00

Here, Freon-11 and Freon-12 are used as both pneumatogen and solvent. Vinac B-7 is a low molecular weight polyvinyl acetate resin.

In the present program, both one-pint (ca. 500 ml) glass pressure bottles and 800-ml stainless steel cylinders were used as foam solution containers. The use of the steel cylinders was mandatory when gases with vapor pressures higher than that of methyl chloride (59 psig) were used. The use of steel cylinders also permitted the use of valves and pipe fittings to permit the generation of foam under water.

### 3.2 EVALUATION OF POLYMERS

A preliminary but important evaluation was conducted on polystyrene and polyvinyl acetate foam systems. Foam solutions were prepared according to the two formulations listed under section 3.1. Steel cylinders were used as containers and they were installed in a 55-gallon drum so that they could be opened and discharge foam under 18 inches of water (Figure 1).

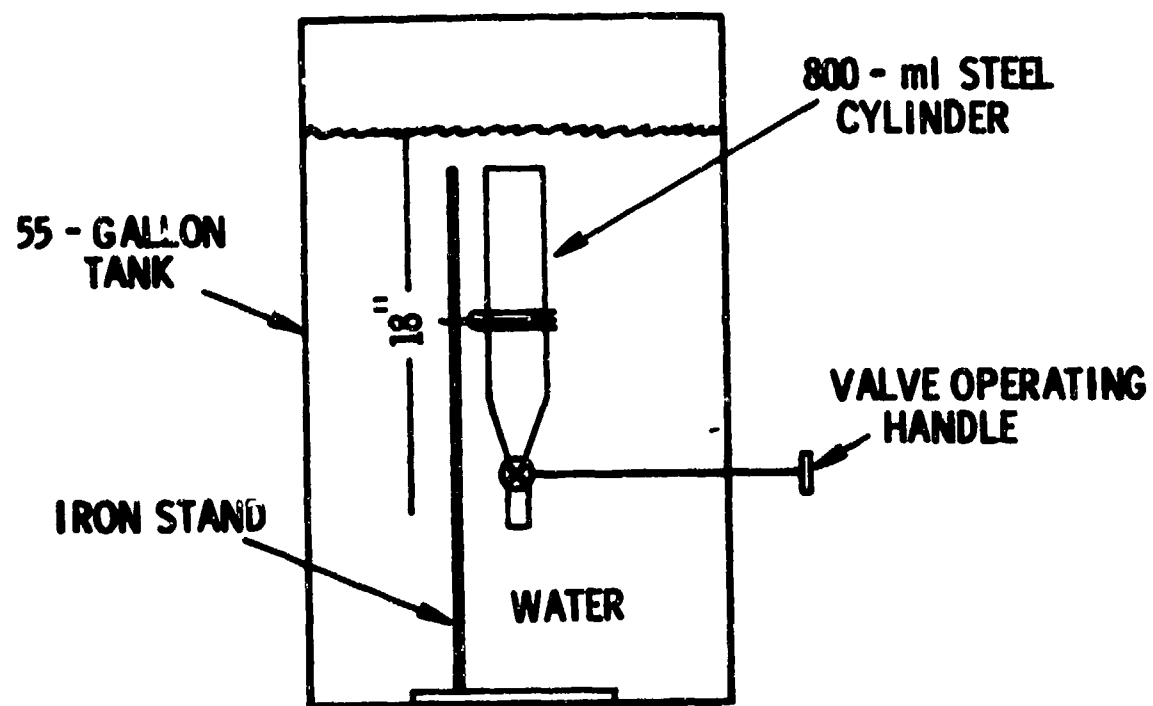


Figure 1. Set-up for Foam Discharge Under 18 Inches Water

The cylinder was held in position by means of an iron stand and the necessary clamps. The cylinder valve was operated by a connecting rod that could be turned from outside the 55-gallon tank. The polystyrene foam came out of the cylinder smoothly when the discharge tank was placed under 18 inches of water. Its density was 1.7 lb/cu ft. A sample of this polystyrene foam was cut off, and a weight was attached to it by a cord. The foam and weight were placed in a large beaker of water and observed for its flotation characteristics. After one week, there was no apparent loss in the buoyancy of the foam.

The polyvinyl acetate foam system was tested in a similar manner. The rate of foam generation was much slower than with polystyrene. The polyvinyl acetate foam density was 1.8 lb/cu ft. During the flotation test the cord attaching the weight to the foam cut into the foam within one hour. The experiment was repeated with similar results. Examination of the foam after water immersion revealed it had become quite soft and weak because of water plasticization. Because of this structural weakness after water immersion, polyvinyl acetate did not appear to be a promising candidate for small vessel flotation. It was not investigated further during this program.

### 3.3 LOW TEMPERATURE OPERATION

The polystyrene instant foam system at the start of the present program relied on either dimethyl ether or methyl chloride as the primary solvent/pneumatogen for the polymer. Secondary solvents were either Freon-11, Freon-12, or Freon-21. The vapor pressures of these compounds are listed in Table 1. At 32°F (0°C), their vapor pressures are reduced to less than one-half of the value at 75°C (24°C). At -22°F (-30°C), their vapor pressure values are below atmospheric pressure. Since operation at -22°F was a goal of this program, it was evident that liquefied gases of higher vapor pressure should be evaluated.

#### 3.3.1 Evaluation of High Pressure Gases as Solvent/Pneumatogens

Four high pressure gases were selected as possible solvent/pneumatogens for low temperature operation. These gases were propylene, propane, Genetron 115, and Freon 13B1. Their vapor pressures at different temperatures are also listed in Table 1.



Table 1. Vapor Pressure of Eight Compressed Gases at:

Gas	Chemical Formula	Vapor Pressure (psia)				
		Different Temperatures (lb/in. <sup>2</sup> absolute)				
		75°F (24°C)	32°F (0°C)	18°F (-8°C)	-15°F (-26°C)	-22°F (-30°C)
Dimethyl ether	(CH <sub>3</sub> ) <sub>2</sub> O	85	39	29.2	13.5	11.8
Methyl Chloride	CH <sub>3</sub> Cl	80	37	28	13.2	11.3
Propylene	C <sub>3</sub> H <sub>6</sub>	112.7	85	68	35.6	31.3
Propane	C <sub>3</sub> H <sub>8</sub>	132	66.5	53.5	28.2	24.5
Freon -11 (Trichlorofluoromethane)	CCl <sub>3</sub> F	14.7	5.8	4.2	1.7	1.3
Freon -12 (Dichlorodifluoromethane)	CCl <sub>2</sub> F <sub>2</sub>	91.5	43	33.7	16.8	14.5
Freon -21 (Dichlorofluoromethane)	CHCl <sub>2</sub> F	25.2	10.3	7.3	3	2.4
Genetron -115 (Chloropentafluoroethane)	C <sub>2</sub> ClF <sub>5</sub>	127	63.5	49	23.7	21
Freon -13B1 (Bromotrifluoromethane)	CBrF <sub>3</sub>	227	140	98	52.5	46

\*From "Matheson Gas Data Book", Fourth Edition, The Matheson Company, Inc. (1966).

Although the vapor pressures of all these materials at 75°F are over 100 psia, only propylene, propane, and Freon 13B1 were believed to have a sufficiently high vapor pressure at -22°F (-30°C) to produce a foam. The vapor pressure of Genetron 115 at -22°F may be marginal but both Genetron 115 and Freon 13B1 were believed to be useful in producing a non-burning solvent/pneumatogen system.

To evaluate the solubility of polystyrene in propylene and propane, foam solutions were prepared using the formulation given in section 3.1, but using these gases as direct replacements for methyl chloride. At 75°F (24°C), the foam solutions were discharged from the containers. The polystyrene/propylene foam had a very rough surface and high density (about 8 lb/cu ft). The polystyrene/propane foam composition did not generate foam at all; only gas came out of the container. Evidently, polystyrene does not dissolve readily in propane.

Evaluation work was then concentrated on polystyrene dissolved in mixed solvent/pneumatogen systems. One gaseous component was methyl chloride. The other was a gas with a higher vapor pressure. In these experiments, the vapor pressure of the mixed solvents/pneumatogens was the only propelling force used to push the solution from the cylinder. The formulations tested are summarized in Table 2.

Formulations 1 and 2 containing propylene were tested at 75°F and produced acceptable foams. Delivery rate was good and the foam produced was of good quality.

However, when these foam solutions were discharged at 18°F (-8°C), only a very slow discharge of a small amount of the foam occurred. Various proportions of methyl chloride/propylene were then formulated and similar results were obtained when these foam solutions were discharged at 18°F. Polystyrene/methyl chloride/propane foam solutions (formulations 3 and 4) were also discharged at 18°F, but only negative results were obtained. No useful foam was produced. Methyl chloride/Freon 13B1 and methyl chloride/Genetron 115 (formulations 5 through 8) were also evaluated at 18°F as solvent/pneumatogens for polystyrene. No useful foams were produced.

This work showed that the mixed gases given in Table 2 can be used to produce foams at 75°F, but at lower temperatures (18°F) they do not have a sufficiently high pressure to force the polymer solution from the storage cylinder.

Table 2. Foam Formulation Tested at Low Temperature  
(% Composition)

<u>Formulation No.</u>	<u>Polystyrene</u>	<u>Glass Micro- Balloons</u>	<u>Igepal CO-970</u>	<u>Freon 11</u>	<u>Methyl Chloride</u>	<u>Propylene</u>	<u>Propane</u>	<u>Genetron 115</u>	<u>Freon 113B1</u>
1	62.30	1.19	4.76	3.97	13.89	13.89	-	-	-
2	62.30	1.19	4.76	3.97	20.28	7.50	-	-	-
3	62.30	1.19	4.76	3.97	13.89	-	13.89	-	-
4	62.30	1.19	4.76	3.97	20.28	-	7.50	-	-
5	62.30	1.19	4.76	3.97	13.89	-	-	13.89	-
6	62.30	1.19	4.76	3.97	20.28	-	-	7.50	-
7	62.30	1.19	4.76	3.97	13.89	-	-	-	13.89
8	62.30	1.19	4.76	3.97	20.28	-	-	-	7.50

### 3.3.2 Cooled Foam Solution Over-pressured by an Inert Gas (Nitrogen)

The work described in Section 3.3.1 showed that the vapor pressure of the solvent pneumatogen alone was not sufficient to force foam solution from the cylinder. It appeared that the solutions would have to be overpressured with an inert non-condensable gas. Nitrogen was selected. Three pressure bottles were prepared containing polystyrene dissolved in a mixture of Freon 11 and methyl chloride (Section 3.1). These cylinders were over-pressured to 100 psig with nitrogen. The foam solution was cooled to  $-8^{\circ}\text{C}$ . Upon opening the cylinder valve the foam discharged slowly (up to 3 minutes). The foam produced was of high density (over 6 pounds/cu ft).

Following this experiment a polystyrene/methyl chloride/propylene foam solution (Formula 2, Table 2) was prepared in a cylinder fitted with a valve at each end. (Figure 2). The charged cylinder was cooled to  $-8^{\circ}\text{C}$ . Prior to discharge, a nitrogen line was connected to the upper valve and the cylinder pressurized to 100 psig. Upon opening the lower valve there was an initial rapid discharge of foam. About 69.5% of the material charged was pushed out of the container as foam.

Similar solution was prepared in another two-valve cylinder and cooled to  $-15^{\circ}\text{F}$  ( $-26^{\circ}\text{C}$ ). Nitrogen pressure in this experiment was held to 40 psig. No foam was obtained under these conditions when the lower valve was opened. However, there was a considerable discharge of gas from the cylinder. This appeared to indicate the solution was too viscous to flow through the discharge valve.

### 3.3.3 Specially Prepared Polystyrene/Methyl Chloride/Freon 13B1 Foam

Work reported in Section 3.3.1 indicated that Freon 11, methyl chloride, and Freon 13B1 when used in combination was a poor solvent for polystyrene. However, the use of Freon 13B1 was attractive because it imparted non-burning properties on methyl chloride (section 3.4.2). It appeared to be a way to provide a non-burning, non-explosive solvent/pneumatogen for the foam system. Because of the very low boiling temperature of Freon 13B1, namely  $-72^{\circ}\text{F}$  ( $-58^{\circ}\text{C}$ ) and the consequent high vapor pressure (190 psig at  $70^{\circ}\text{F}$ ) it also appeared likely that its use would help low temperature operation. Because of these considerations a procedure was developed to permit the use of Freon 13B1.

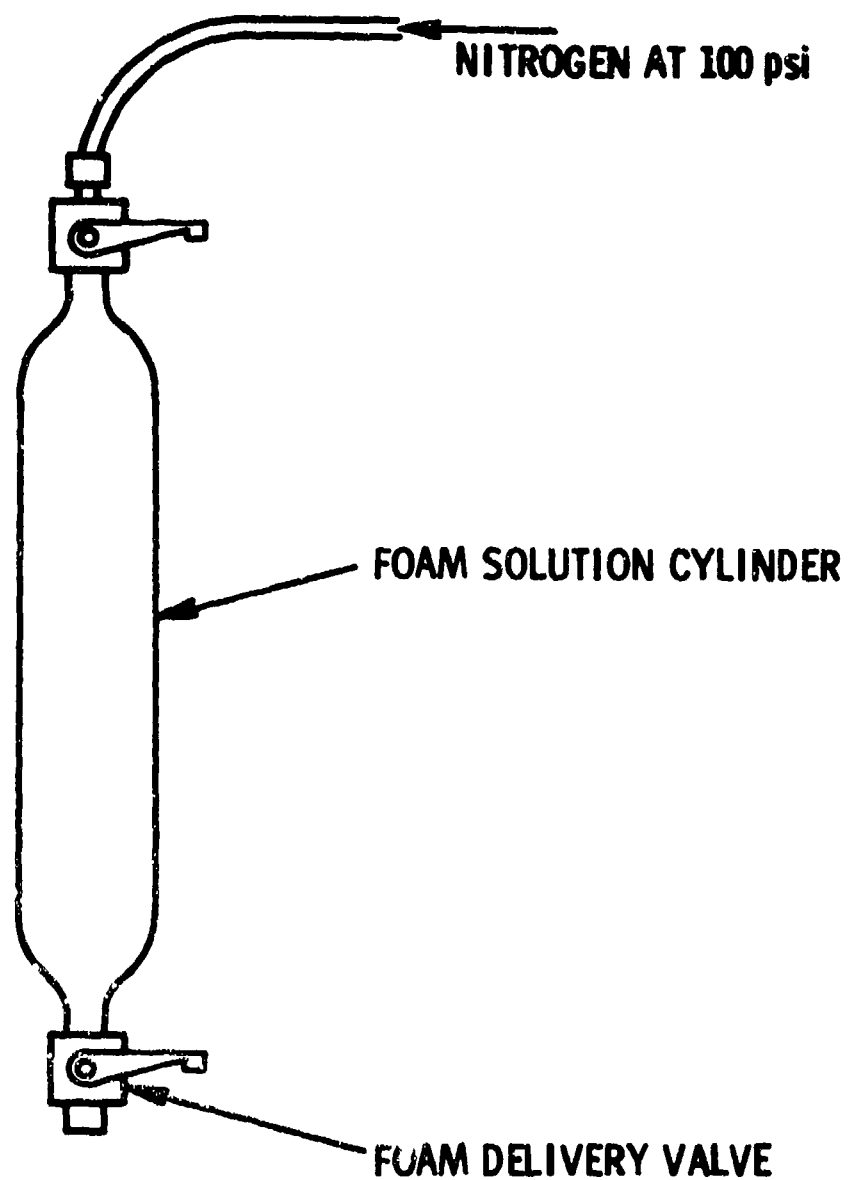


Figure 2. Instant Foam Cylinder with Necessary Valving for Over-pressuring with Nitrogen

Polystyrene foam solutions were prepared in which the Freon 11 normally used was replaced with Freon 13B1. These formulations contained 25.4% methyl chloride and 6.35% Freon 13B1.

These solutions were prepared in a stepwise manner first adding methyl chloride, dissolving the solids, and then adding Freon 13B1. The polystyrene, glass microballoons, Igepal CO-970, and methyl chloride were charged into the cylinder first. The charged cylinder was put on a rotating wheel so that it was tumbled intermittently for at least 16 hours. To insure that the polystyrene was well dissolved in the methyl chloride, the charged cylinder was then put in a 120°F (49°C) room for 24 hours. The charged cylinder was then chilled in dry ice and charged with Freon 13B1 and once more tumbled for 16 hours to ensure good mixing. No nitrogen over pressure was used in preparing these cylinders. The pressure exerted by the solvent/pneumatogen was 75 psi at 75°F and 100 psi at 95°F.

This cylinder was cooled at -8°C and discharged. No nitrogen over pressure was used in this test. The foam delivered represented 84.5% of the material charged to the cylinder. It had a density of 3 lb/cu ft.

No attempt was made to generate foam using this formulation at lower temperatures since delivery was incomplete at 18°F (-8°C). (See section 3.3.4).

#### 3.3.4 Characteristics of "Instant" Type Foam Solutions At Low Temperatures

This work showed the feasibility of producing foam solutions which produce useful foams (3 to 6 pounds per cu ft density) at 0 to -8°C. However, to force these solutions from the storage cylinder it is necessary to over pressure the cylinder with 40 to 100 psig of a non-condensable gas such as nitrogen. An exception to this is the foam formulation using Freon 13B1, described in section 3.3.3. The methyl chloride/Freon 13B1 combination had sufficient pressure to discharge the cylinder at low temperature.

The work also showed that as the solutions are cooled to still lower temperatures the solution becomes so viscous that it does not flow readily from the cylinder and finally at about -15°F (-26°C) flow stops and only gas issues from the cylinder.

It appears likely that at intermediate temperatures (0°C to -10°C or -15°C) the over pressuring gas forces the foam solution to flow from the center of the foam solution forming a cavity along the center line of the cylinder (Figure 3). An increasing amount of the solution is left adhering to the foam walls as the temperature decreases.

At still lower temperatures the solution is so viscous it does not flow at all and only gas dissolved in/or occluded in the solution escapes from the surface exposed by opening the valves.

It thus appears that in a foam solution containing a high percentage of polymer and high vapor pressure gases, viscosity becomes the controlling property. As the temperature drops, the viscosity becomes greater and eventually the flow of solution from the tank stops. The use of a diaphragm or a collapsible tube containing the foam solution with the nitrogen over pressure acting on the back side of the diaphragm or tube appears to be one way to cause these very viscous solutions to flow from their containers. This principle is illustrated in Figure 4. The use of a diaphragm or collapsible tube insures a positive pressure on the foam solution and forces it to flow through the discharge outlet. However, the development of such a system was beyond the scope of the present program and it was not investigated. If the solution can be made to leave the storage cylinder it is probable that it can be made to foam at ambient pressures.

### 3.4 REDUCTION OF FLAMMABILITY

#### 3.4.1 Burning Characteristics of Polystyrene Foam

Polystyrene is a flammable material. Foams made from it when exposed to flame, first melt. Then, if the melt is heated to a sufficiently high temperature, it burns with a smoky flame.

To reduce the flammability of polystyrene foam, an effective fire retardant must be added. Monsanto Company has developed a very powerful proprietary fire retardant for plastics. For higher density polyurethane foam, 0.5 part of this retardant per 100 parts of polymer is sufficient. However, the polystyrene foam is of lower density and two parts of this fire retardant per 100 parts of polymer are required to render the foam non-burning.

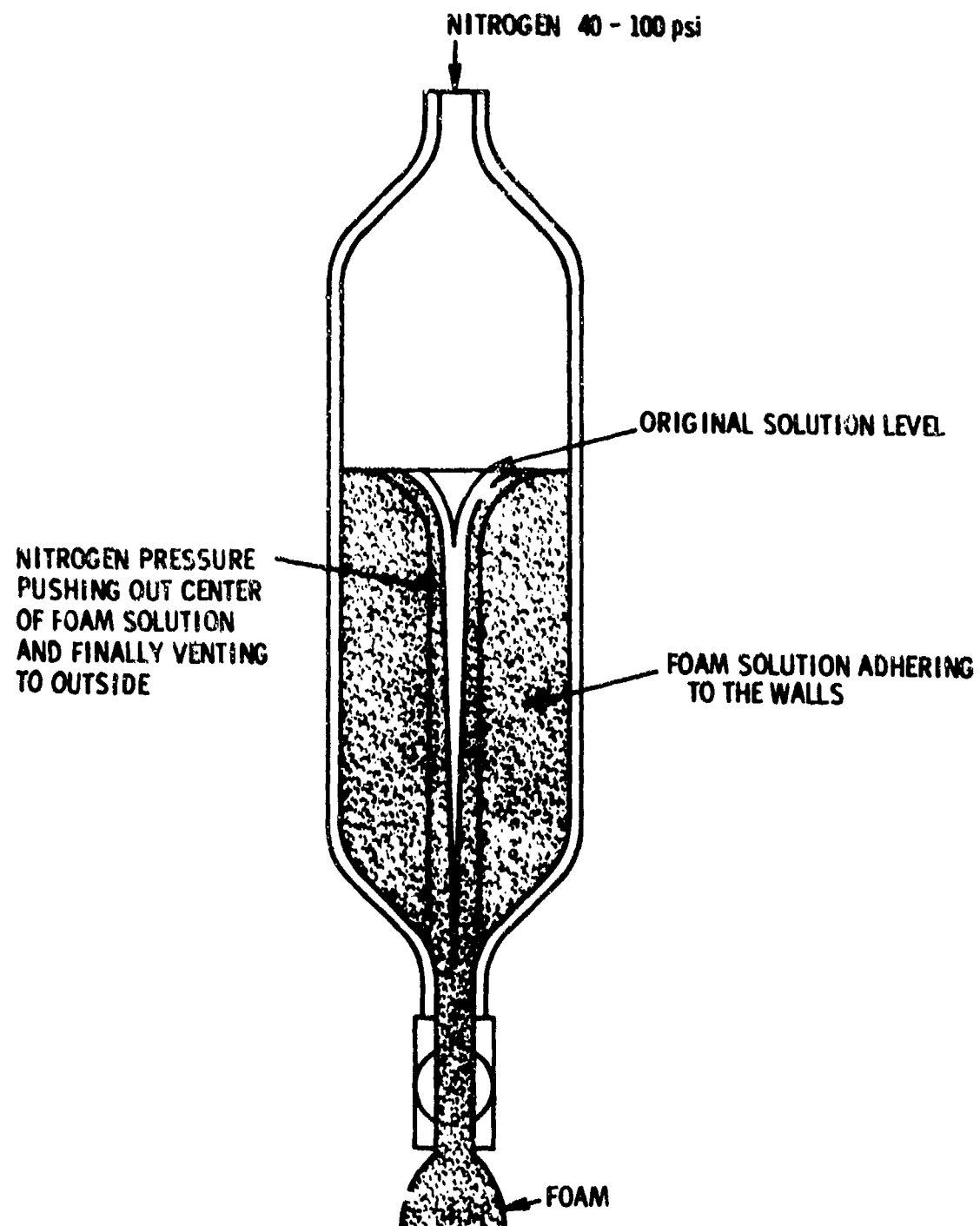


Figure 3. Gas Forcing Its Way Through the Foam Solution



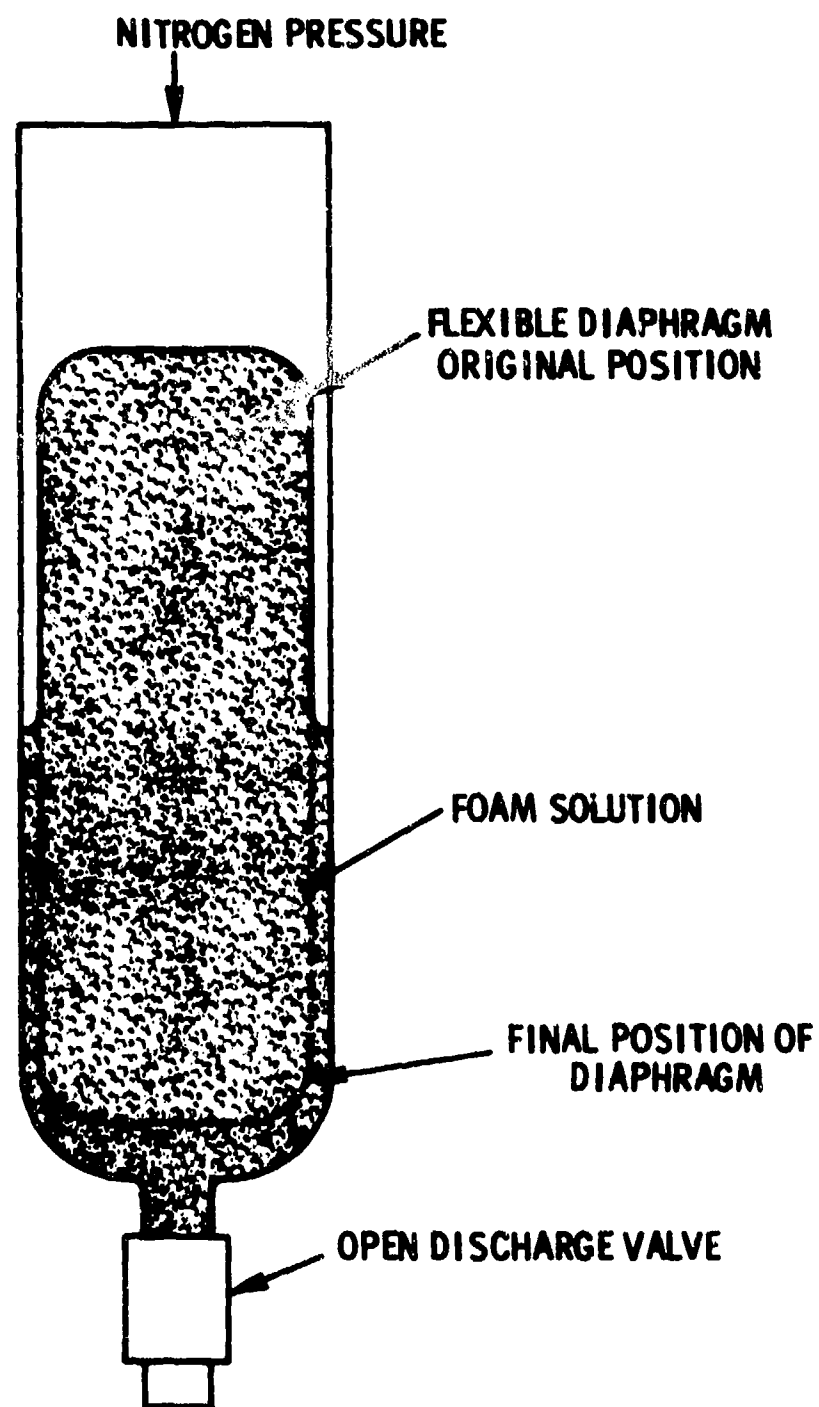


Figure 4. Use of a Diaphragm to Insure Flow of Very Viscous Foam Solution

To determine the burning characteristics of the polystyrene foam, samples containing 2% of the flame retardant were tested using the ASTM D1692 test. In this test, a sample of foam held in the horizontal position and supported by a metal screen is ignited by a flame. After ignition, the flame is removed and the sample is observed for the extent and time of burning. In the case of the samples prepared during this program, burning of the sample stopped when the source of ignition was removed. These tests show that these foams are non-burning in the absence of an outside source of ignition.

In addition to the ASTM burning test, 3 x 3 x 1 inch samples of the foam were tested in an automatic combustion gas analyzer developed by Monsanto Research Corporation. The samples were exposed to two test conditions. In one, the sample was exposed to both radiant heating and flame (F). In the other, it was exposed to radiant heating only (NF).

Measurements were made of smoke obscuration (Dm) and evaluation of gaseous combustion products (CO, CO<sub>2</sub>, NO<sub>x</sub> and hydrocarbons) and oxygen consumption by the samples under flame and non-flame ignition conditions. The results were similar to those obtained with commercial fire retardant polystyrenes such as ARCO M-57A and M405B, BASF BF 55, Foster-Grant FG 4486, and Monsanto Company Lustrex 300 FR.

The fire-retarded polystyrene produced essentially the same combustion products as are generated by conventional polystyrene. The reason for this is that with both fire-retarded and conventional polystyrene, the bulk of the material exposed to heat and flame from the outside source is the same. The only difference is that the fire-retarded polystyrene generates more CO, more hydrocarbons, and a higher smoke concentration due to its less complete combustion.

For samples exposed to flame, ignition was delayed 3.9 minutes. With the samples exposed to radiant heating, ignition never occurred.

Table 3 presents the data from these tests. The significance of the data and the rationale for the tests are described in references 1 and 2. The original data, along with plots of smoke and vapor generation for these tests, are included in the Appendix.

Table 3. Combustion Test Results of Fire Retarded Polystyrene Instant Foam

Maximum Combustion Products and  
Minimum Oxygen Concentrations

Smoke		F	NF
Dm		309	164
Dmwt (g.-l)		4.46	2.08
Dmwc (g.-l)		4.67	4.25
Time to Ds = 16 (min.)		3.9	5.2
Time to Dm (min.)		6.4	30

Time to Attain Maximum Combustion Products  
and Minimum Oxygen Concentrations  
(min.)

	F	NF
CO	30	30
CO <sub>2</sub>	30	30
HC	25	30
NO <sub>x</sub>	30	30
HBr	30	30
O	30	30

Notes:

\* Includes CO<sub>2</sub> produced by propane burner flames (~1%).

\*\* NO<sub>x</sub> produced by flames from sample and from burner.

\*\*\* Approximate CO<sub>2</sub> contributions from propane flames has been subtracted.

Symbol explanation:

F Sample exposed to radiant energy and flame.

NF Sample exposed to radiant energy only.

Dm Smoke optical density, maximum.

Ds Specific smoke optical density

Dmwt Total-mass-normalized smoke

optical density.

Dmwc Consumed-mass-normalized smoke

optical density.

Weight-Based Combustion Products Data  
Max. Values with Reference to Sample Weight  
(g./kg.)

	F	NF
CO	56.6	4.7
CO <sub>2</sub>	3164*	41.4
HC as methane	17.2	1.09
NO <sub>x</sub>	1.7	0.06
HBr	5.4	5.9

Time to reach D<sub>s</sub> = 16. Indication of  
smoke development time.

g.-l Per gram of sample.

ppmv Parts per million by volume.

% Percent by volume.

HC Hydrocarbons

### 3.4.2 Flammability of Solvent/Pneumatogen

As mentioned earlier (section 3.1), methyl chloride was used instead of dimethyl ether as the solvent for polystyrene in order to lower the flammability level of the solvent/pneumatogen system. However, methyl chloride is still a combustible chemical. It was desirable to develop a non-combustible gas mixture for use in the polystyrene foam system for small vessel flotation. The burning characteristics of candidate solvent/pneumatogen gases are listed in Table 4.

The principal gases of interest as solvent/pneumatogens for polystyrene foams are methyl chloride, propylene, propane and Freon 13B1 (bromotrifluoromethane). Because of their potential utility for low temperature operation, the flammability of mixtures of these gases was determined

All tests were run with methyl chloride (a known solvent for polystyrene) as one component of the mixture. The composition of the gas mixtures covered the range of 80 to 40% by weight of methyl chloride with the remainder (20-60%) being either propylene, propane, or Freon 13B1.

The following test procedure was used to determine the combustibility of the gas mixtures. Methyl chloride was weighed into a steel cylinder (~250 ml) and then the desired amount of the second gas was added to the cylinder. The gas mixture was allowed to mix well by tumbling it for 30 minutes.

The cylinder was then set upright in a hood and its contents were released through the slightly opened valve. The escaping gas mixture was ignited with a flame from a propane torch. Observations were made of whether the mixed gases continued to burn after the propane torch was removed, and whether the gas mixture changed its burning characteristics as the discharge of gas continued. The results of the burning tests are summarized in Table 5.

**Table 4. Burning Characteristics of Liquefied Gases of Potential Interest in Instant Foam (Matheson Gas Data Book (1961) and Guide for Safety in the Chemical Laboratory (D. Van Nostrand Company, Inc., 1954))**

Compound	Boiling Point °F (°C)	Flash Point °F (°C)	Auto Ignition Temperature °F (°C)	Flammable Limits in Air %
Dimethyl ether	-12.7 (-24.8)	> -42° (-41)	662 (350)	3.4 to 18
Methyl Chloride	-11.4 (-24.1)	-	1170 (632)	10.7 to 17.4
Propylene	-53.9 (-47.7)	-	927 (497)	2.4 to 10.3
Propane	-43.8 (-42.1)	-	874 (468)	2.2 to 9.5
Freon 11	74.8 (23.8)	-	-	nonflammable
Freon 13B1	-72 (-57.6)	-	-	nonflammable
Genetron 115	-	-	-	nonflammable
Freon 12	-21.6 (-29.3)	-	-	nonflammable

Table 5. Burning Characteristics of Gas Mixtures

<u>Gas Mixture (Range of Composition)</u>	<u>Burning Characteristics of Gas Mixture</u>	
	<u>Initial Flow</u>	<u>Continued Flow</u>
Methyl Chloride/Propylene 80/20% to 40/60%	non-burning	burns
Methyl Chloride/Propane 80/20% to 40/60%	non-burning	burns
Methyl Chloride/Freon 13B1 burning 80/20%	non-burning	non-burning

The mixtures of methyl chloride with both propylene and propane were initially non-burning but as flow continued the mixture became flammable.

The 80% by weight methyl chloride, 20% Freon 13B1 mixture was non-burning during the entire discharge of the supply cylinder.

The results of the burning test along with the performance of methyl chloride/Freon 13B1 during work on low temperature foam generation (section 3.3.3) led to the selection of this gas mixture as the solvent/pneumatogen system for the final formulation which is being tested for long-term shelf stability (section 3.7.2).

#### 3.4.3 Safety of Foam System in Fire Situation

The foam system in the undeployed state, with the solution within the pressure tank, presents the same hazards as any compressed gas stored in tanks exposed to heat and fire. As the temperature of the tank rises, so does the internal pressure. As long as the internal pressure remains below the bursting pressure of the tank, the charge is isolated from the fire and does not burn or decompose. The problem of safety for the tanks and foam solution thus requires proper tank and pressure relief valve design.

During discharge of foam in the presence of a fire, the methyl chloride/ Freon 13B1 solvent/pneumatogen will not burn and may even act as a flame suppressant or extinguishing agent. This was not demonstrated experimentally during the program reported on, however.

The foam itself can be made non-burning after deployment by use of fire retardants. However, in the presence of a fire from other sources (fuel, wood, etc.), the foam will decompose and even burn weakly. Under these conditions, the foam behaves like most organic materials, giving off carbon dioxide, carbon monoxide, oxides of nitrogen, and other degradation products. These products of combustion can be toxic if breathed. This is particularly true if a person is exposed to them in a closed space where high concentrations of these gases can build up. The hazards connected with exposure to the gases generated by these foams is the same as those associated with exposure to the smoke and gases generated by any fire.

### 3.5 FOAM GENERATION UNDER 15 FEET OF WATER

As described in Section 3.2, the polystyrene instant foam system did work under 18 in. of water. However, one of the objectives of this program was to determine the performance of the instant foam system under 15 feet of water. For these experiments, a test tank was built that provided the necessary head of water.

#### 3.5.1 Test Facility for Foam Generation Under 15 Feet of Water

Figure 5 shows the test facility. The test tank consisted of an open-top 55-gallon drum along with its lid, seal and clamping ring. Two valves were attached to the 55-gallon tank near the bottom. One valve was used for controlling water flow to the tank; the other was in the tank drain line. Two 4 in. diameter windows of Plexiglas were installed near the top of the tank for lighting and observing the generation of foam inside the tank. The tank lid was provided with a 4 inch connection for the plastic stand pipe and a pipe connection so that the foam solution cylinder could be assembled to the tank. A piece of circular rigid metal grid was attached to an extension of the foam connector pipe. This grid was at about the 6 inch level in the tank and served to prevent the foam from floating up and blocking the stand pipe entrance.

The stand pipe was made of polyvinyl chloride pipe (schedule 80 NSF) and was 4 in. in diameter and 15 ft. long. It was threaded into a 4 in. pipe coupling welded to the tank lid. The pipe stood vertically and provided the necessary head to

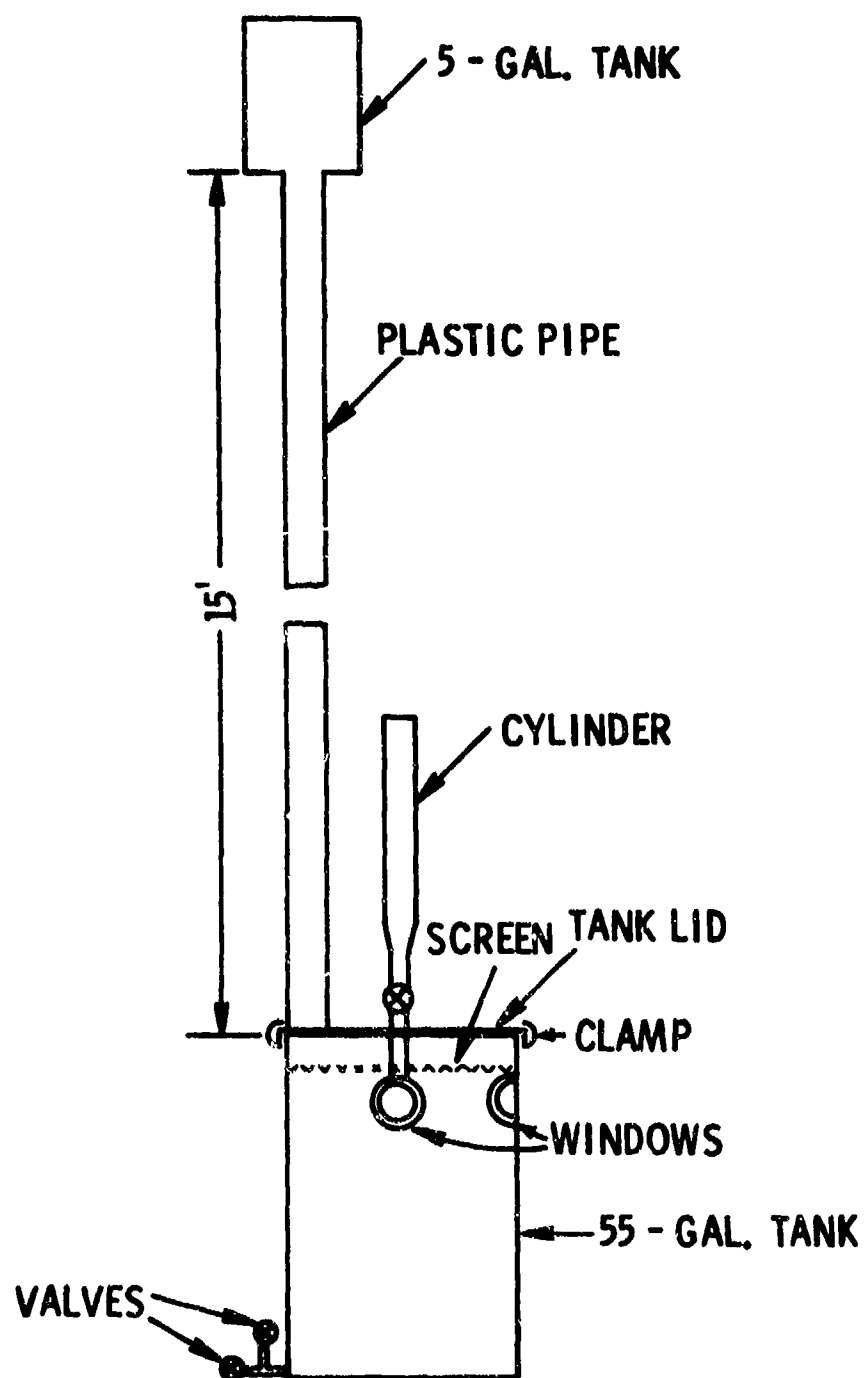


Figure 5. Set-up for Foam Generation Under 15 Feet of Water



produce 6.5 psi of pressure. A 5-gallon surge tank was assembled to the upper end of the stand pipe. Figure 6 shows the tank assembly with a solution cylinder in place.

### 3.5.2 Test Procedure

Foam generation under 15 ft. of water was conducted in the following manner. The tank was closed with the lid clamped tightly in place. Water was added until the tank was filled. At this point, the foam solution cylinder was assembled loosely to its pipe connection on top of the tank. Water was added until the stand pipe was filled to the 15 ft. level. As water rose in the stand pipe, it also rose in the pipe connection for the cylinder. When water began to come out of this connection, the cylinder connection was drawn up tight. This insured that there was water up to the cylinder valve. The interior of the test tank was illuminated by a lamp placed close to one of the windows. Opening the cylinder, valve generated the foam within the tank. Figure 7 shows the foam coiled up inside against the viewing port.

Four tests were carried out. Each time, the foam came out of the cylinder smoothly. The water displaced by the foam was collected in the 5-gallon surge tank on top of the plastic pipe. The volume of water displaced into the surge tank was a measure of the volume of foam produced. Motion pictures were taken during the last run. The results of these tests are summarized in Table 6.

### 3.6 WATER ABSORPTION OF POLYSTYRENE FOAM WHEN IMMERSSED IN 15 FEET OF WATER

During the underwater foam generation tests, it was noticed that when the foam remained under 15 feet of water overnight, it absorbed a considerable amount of water. It was also observed that this water did not readily drain from the foam. A 50 g sample of foam which had absorbed 209 g of water, lost only 102 g of water after hanging suspended in air for one week.

However, there was no noticeable increase in the weight of a fresh sample of foam floated on or just under the surface. Water absorption appeared to be associated with immersion under a considerable head of water.

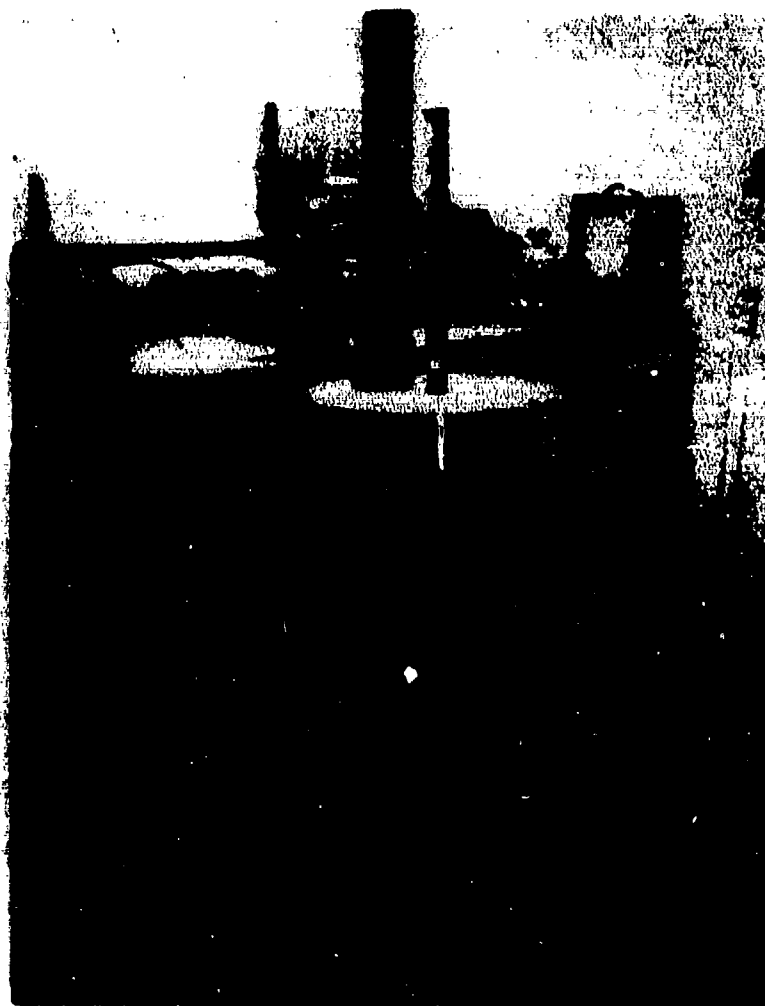


Figure 6. Assembled Foam Test Stand



Figure 7. Foam Generated Under Water Viewed  
Through Tank Viewing Port

Table 6. Test Results of Polystyrene Instant Foam Generation Under 15 Feet of Water

Run No.	Date	Formulation	Shape of Foam	Approx. Vol. of Water Displaced in 5-gal. Tank (cc)	Remarks
1	7-14-75	Standard with Triton -200	3"-4" dia. rod curled in coil	8000	Foam was kept under 15 ft of water overnight and absorbed water that weighed about 4 times the weight of foam.
2	7-16-75	Standard with Triton -200	3"-4" dia. rod curled in coil	8500	Foam was kept under 15 ft of water for 1 hour and absorbed water that weighed about 2 times the weight of foam.
3	8-27-75	Standard with Isopal CO-970 instead of Triton -200	2"-3" dia. rod curled in coil	8000	Foam was generated from a smoothed valve outlet. It absorbed water like that of Run 2.
4	9-28-75	Standard with Isopal CO-970 instead of Triton -200	2"-3" dia rod curled in coil	8000	Foam was taken out right after generation. It did not absorb water.

### 3.6.1 Evaluation of Waterproofing Agents

Waterproofing or water-repellent materials were first evaluated for utility in reducing water absorption. Polystyrene foam solutions were prepared with the addition of various waterproofing agents, namely, Dow Corning Silicone 200 fluid, zinc stearate, sodium silicate, Fisher Bath Wax, Carnauba wax, and paraffin wax. Some of these materials (e.g., waxes) did not mix well with the foam solution. None of these materials was effective in preventing water absorption by polystyrene foam when immersed in water.

### 3.6.2 Effect of Cell Size

Two samples of polystyrene foam made during the program were tested for open cell content. Both samples had over 80% open cells. Foams with closed cells were also made. These foams had relatively large cells and heavy cell walls. However, when these foams were soaked in water, water permeated through the cell wall and remained within the cells when the foams were taken out of the water. Drainage was very slow from these foams. Some of them still contained liquid water approximately one month after being removed from the water. Very fine-celled foam samples also absorbed a considerable amount of water during immersion under a 15-foot head.

### 3.6.3 Quantitative Water Absorption Under 15 Feet of Water

Evidently, the polystyrene foam cell wall is easily permeated by water, especially when exposed to 15 feet of water pressure (6.5 psi). However, these samples remained floating throughout the tests. Thus, the water absorption did not eliminate the buoyancy of polystyrene foam completely. Two series of tests were run to determine the extent of the water absorption by polystyrene foam kept under 15 feet of water for different time intervals.

One test was run on foam generated under 15 ft. of water. This foam was small celled and had a density of 1.5 lb/cu ft. Immediately after the test, the foam mass was removed from the test tank and cut into six, pieces of approximately equal volume. Each piece was weighed and the pieces were then returned to the test tank under a 15-foot head of water.

The second test was run on foams made in air. This foam was made without nucleating materials and had very large cells. Cell size ranged from 1/4 to 1 inch in effective diameter. Examination of the cell walls indicated they were intact; thus this was an apparently closed-cell foam. The membranes also appeared to be heavy. Six pieces of this foam were cut and weighed and then placed in the test tank and tested under 15 feet of water.

Sample pieces of each foam were removed from the tank at intervals and weighed. The weights after water immersion were compared to the initial weights and the percent gain in weight recorded.

$$\frac{\text{Weight after immersion} - \text{Initial Weight}}{\text{Initial Weight}} \times 100 = \text{Water Absorption (\%)}$$

The results of this test are summarized in Table 7.

Table 7. Water Absorption by Foam Immersed Under 15 Feet of Water and Net Buoyancy

Soaking Time (hours)	Fine Cell Generated under Water		Large Cell Foam Generated in Air	
	Water Absorption (% Original Wt)	Net Buoyancy (lb/cu ft)	Water Absorption (% Original Wt)	Net Buoyancy (lb/cu ft)
0	0	60.5	0	60.5
2	300	56	500	53
4	450	54	1000	46
6	500	53	1000	46
8	600	52	1500	38
16	700	50	1500	38
24	700	50	1500	38

Assume the initial foam density = 1.5 lb/cu ft and water density = 62 lb/cu ft.

The large-cell foam absorbed approximately twice as much water as the fine-cell foam. Apparently, an equilibrium was reached in about 8 hours and no more water was absorbed during the remainder of the test. This assumption is borne out of the following calculation:

Assume 1 cu ft of foam with a density of 1.5 lb/cu ft.  
 1 cu ft = 28317 cc  
 1-1/2 lb of polystyrene = 752 cc of dense polystyrene

Subtracting, there would be 27565 cc of gas space in the foam.

After 8 hours water immersion the foam, which initially weighed 1.5 lb, weighed 22.5 pounds. Therefore, it absorbed 21 pounds (9534 cc) of water.

Assume a closed container that contains 27,565 cc of gas under 1 atmosphere (14.7 psi) pressure. If water is forced into this container under 6.5 psi (0.44 atm) pressure, sufficient water will enter the container until the internal pressure equals the external pressure forcing the water into the container. This amount of water can be calculated as follows:

$$\frac{p_1}{p_2} = \frac{V_2}{V_1}$$

where  $p_1 = 1$  atm.

$p_2 = 1.44$  atm.

$V_1 =$  initial volume of gas  
 (27,565 cc)

$V_2 = \frac{27,565}{1.44} = 19,113$  cc

$27,565 - 19,113 = 8452$  - theoretical amount of water forced into the container

Actually, 9534 cc of water were absorbed. The difference, 1082 cc, probably represents water trapped in broken cells, in fissures and cracks of the foam and that which wets the extensive foam surface. The data on which this calculation is based contains several assumptions. However, the calculations appear to bear out that there is an equilibrium amount of water the foam can absorb and that the large-cell foam used in this experiment probably attained such equilibrium.

The tests run on the small-cell foams were very encouraging. Water pick-up was reduced by more than one-half of that of the large cell foam and the loss in buoyancy was not prohibitively high. The foam had an initial density of 1.5 lb/cu ft. This density of foam would provide approximately 61 pounds of buoyancy. After 24 hours the foam had increased in weight some 700%. It then has a density of  $1.5 \times 8 = 12$  lb/cu ft. The buoyancy after 24 hours is  $62.4 - = 50.4$  lb/cu ft. This represents a loss of approximately 20% of the original buoyancy.

These foams were completely immersed in water and all surfaces of the foam were wetted. In an actual ship situation the foam would probably be deployed in a compartment and wetting of the foam surfaces might not be complete. If complete wetting is assumed, it appears that it would be desirable to provide 20% excess flotation capacity in the actual shipboard installation. This would compensate for the water absorption that might occur in 24 hours. A 15 foot depth may be conservative for a real situation.

### 3.7 SHELF LIFE

Polystyrene foam solutions in the past have been stored over one year in our laboratory without noticeable change. For this program, two experiments were conducted to determine the shelf life of the instant polystyrene foam system. They are discussed in the following sections.

#### 3.7.1 Short Term Storage at Different Temperatures

Two identical samples were prepared in 500 ml glass pressure bottles each containing the polystyrene foam formulation described in section 3.1. One bottle was stored at 120°F (49°C) room and the other was stored at 72°F (22°C). After 20 days of storage, the contents in both bottles appeared the same, and when opened, they discharged at the same rate. Each bottle was completely emptied. The foam density was 1.0 to 1.3 lb/cu ft for each foam. There was little or no difference in the appearance of the two foams.

#### 3.7.2 Long-Term Storage at 70-75°F (21-24°C)

Two 800-ml steel cylinders were charged, each with the following formulation. This formulation was the one developed during this program and was the result of the work on low temperature operation and reduction of flammability.



	<u>Wt (g)</u>
Lustrex HH101	263
Glass microballoons (1G101)	5
Igepal CO-970	17
Methyl chloride	137
Monsanto Co. proprietary fire retardant	5.3
Freon 13B1	34

The charging procedure was the same as that described in section 3.3.3.

One charged cylinder is being stored in our laboratory for 18 months (17 September, 1975 through 16 March, 1977). The other cylinder was discharged on 16 September, 1975. The following data were recorded on the discharge of this cylinder and the properties of the resulting foam:

a. Time to discharge	1 second
b. Appearance of foam	uniform small cell, white-colored
c. Stability of foam	no volume change after discharge
d. Foam density	0.8 lb/cu ft
e. Compressive strength	
at yield	6.51 psi
at 30% compression	5.86 psi
at 60% compression	5.47 psi
f. Percent open cells	83.2
g. Number of cells/inch	30

The percent open cells appears to be abnormally high. It may reflect the effect of the use of the higher pressure Freon 13B1 as a part of the solvent system.

The above data will serve as a basis of comparison for the foam which will be generated after 18 months of storage.

#### 4. CONCLUSIONS

From this work, it can be concluded that polystyrene foam which provides 60 to 61 lb/cu ft of flotation can be generated at a water depth of 15 feet. If the foam is left immersed in water at that depth there is a 20% loss in flotation power in 24 hours. This loss of flotation comes from water being absorbed into the foam. The exact mechanism of water absorption is not known at this time. It may be by water diffusion through intact cell walls, breaking of cell walls by the water pressure, or water entrance into already open cells. However, fine celled foams are definitely more resistant to water pick up than are large celled foams.

Non-burning solvent/pneumatogen systems for the foam solution have been developed. These systems are based on mixtures of methyl chloride and Freon 13B1.

A non-burning polystyrene foam containing only 2% by weight of a flame retardant additive has been developed.

Operation at 14°F (-10°C) is feasible. Operation at temperatures as low as -22°F (-30°C) does not appear feasible using a simple pressure tank. Failure to operate at low temperatures appears to be due to the very high viscosity of the polymer solution at low temperatures. The solution will not flow out of the container under these conditions. If the delivery of foam solution to the outside of the pressure container can be solved, foam formation at temperatures lower than 14°F appears possible.

Up to this time, storage stability does not appear to be a problem with the foam systems developed.

It can be concluded from this work that providing flotation to small vessels in distress using foams is a feasible concept that should be developed further.

## 5. RECOMMENDATIONS FOR FUTURE WORK

It is recommended that this work be continued with particular emphasis on the following areas:

- . Reduction of the water absorption by the foam when immersed under 15 feet of water.
- . Improvement of foam generation at low temperatures, and
- . Development of prototype equipment to be installed and demonstrated in a small vessel.

Specific recommendations in these areas are as follows:

### 5.1 REDUCTION OF WATER ABSORPTION

Work should be done to reduce the amount of water absorption of these foams when they are immersed in 15 feet of water. This work should entail the following:

- . Producing as fine-celled a foam as possible.
- . Toughening of the foam cell walls.
- . Reduction of open cell content to a minimum, and
- . Determining the feasibility of enclosing the foam in a water-impermeable film. This film could be a part of the foam generating equipment and be deployed only at use time.

### 5.2 LOW TEMPERATURE OPERATION

This work should concentrate on the following:

- . Providing the foam solution tanks with a diaphragm which separates the propellant gas (nitrogen), which is necessary at low temperatures, from the foam solution. The diaphragm would furnish a positive means of forcing the highly viscous foam solution from the tank and would prevent gas channeling through the solution.
- . Determining the feasibility of using heaters and/or insulation to maintain the foam solution at more nearly normal temperatures

### 5.3 DEVELOPMENT OF PROTOTYPE EQUIPMENT

The design and fabrication of an adequate foam system to be installed in a small vessel should be a part of a future program. This would include the design of the necessary tanks, mounting frames and brackets, the actuating means to deploy the foam, and the necessary plumbing and utilities to make the system effective. After design is complete, prototype equipment should be built for demonstration on an actual fishing vessel or other small ship.

APPENDIX

ORIGINAL BURNING DATA AND PLOTS OF COMBUSTION  
PRODUCT CONCENTRATION

# Flame Exposure Conditions

## UNCLASSIFIED COMBUSTION PRODUCTS ANALYSIS REPORT

### Specimen Description

Sample Number

Material

Sample Composition

Weight (g)

Weight Loss (g)

Weight Loss (%)

Sample Dimensions (cm)

Other

PREPS

3.1469

3.0091

95.6

7.6 x 7.6  
(2 pcs. compressed)

Date

Requester

Requesting Organization

MRC Job No.

Material Page No.

Exam. comment Made by

10-10-75

Sam Sun

MRC

6948

J. Miller

S. Barksdale

### Specimen Labels

Combustion Chamber

Sample Orientation

Imposed Energy Flux (watts/cm<sup>2</sup>)

Flame Impingement

Fire Load (kg/m<sup>2</sup>)

Combustion Chamber Temperature (°C)

Initial

Maximum (time)

Time

Replication

NBS-Aminco

Horizontal

2.5

Yes F

6.2 x 10<sup>-3</sup>

50-55

### Observations During Measurement

Ignition

Flaming

Smoking

Dripping

Intumesce

Other

### MEASUREMENT RESULTS

Data Reported

- ☒ Single Experiment
- ☐ Multiple Experiments Under Identical Conditions
- ☐ Average Values for Multiple Experiments Under Identical Conditions
- ☐ Average Values for Both Flaming and Nonflaming Test Conditions

### Tests

$\dot{Q}_h$

$\dot{Q}_{net}$  (kW)

$\dot{Q}_{net}$  (kW)

Time to  $\dot{Q}_{h,16}$  (min)

Time to  $\dot{Q}_h$  (min)

### Maximum Combustion Products and Minimum Oxygen Concentrations

CO (ppmv)

CO<sub>2</sub> (%)

HC, as methane (ppmv)

NO<sub>x</sub> (ppmv)

HCH (ppmv)

HCl (ppmv)

HBr (ppmv)

O<sub>2</sub> (%)

Other

### Times to Attain Maximum Combustion Products and Minimum Oxygen Concentrations (min)

CO

CO<sub>2</sub>

HC

NO<sub>x</sub>

HCH

HCl

HBr

O<sub>2</sub>

Other

### Weight-based Combustion Products Data. Maximum Values With Reference to Sample Weight (g/hr)

CO

CO<sub>2</sub>

HC as methane

NO<sub>x</sub>

HCH

HCl

HBr

Other

56.6

3164

17.2

1.7

5.4

### EC = (AT) Values for 30-Minute Sample

CO (ppmv-min)

CO<sub>2</sub> (%)

HC (ppmv-min)

NO<sub>x</sub> (ppmv-min)

HCH (ppmv-min)

HCl (ppmv-min)

HBr (ppmv-min)

Other

### Times to Reach Specific EC = (AT) Values

CO

CO<sub>2</sub>

HC

NO<sub>x</sub>

HCH

HCl

HBr

O<sub>2</sub>

Other

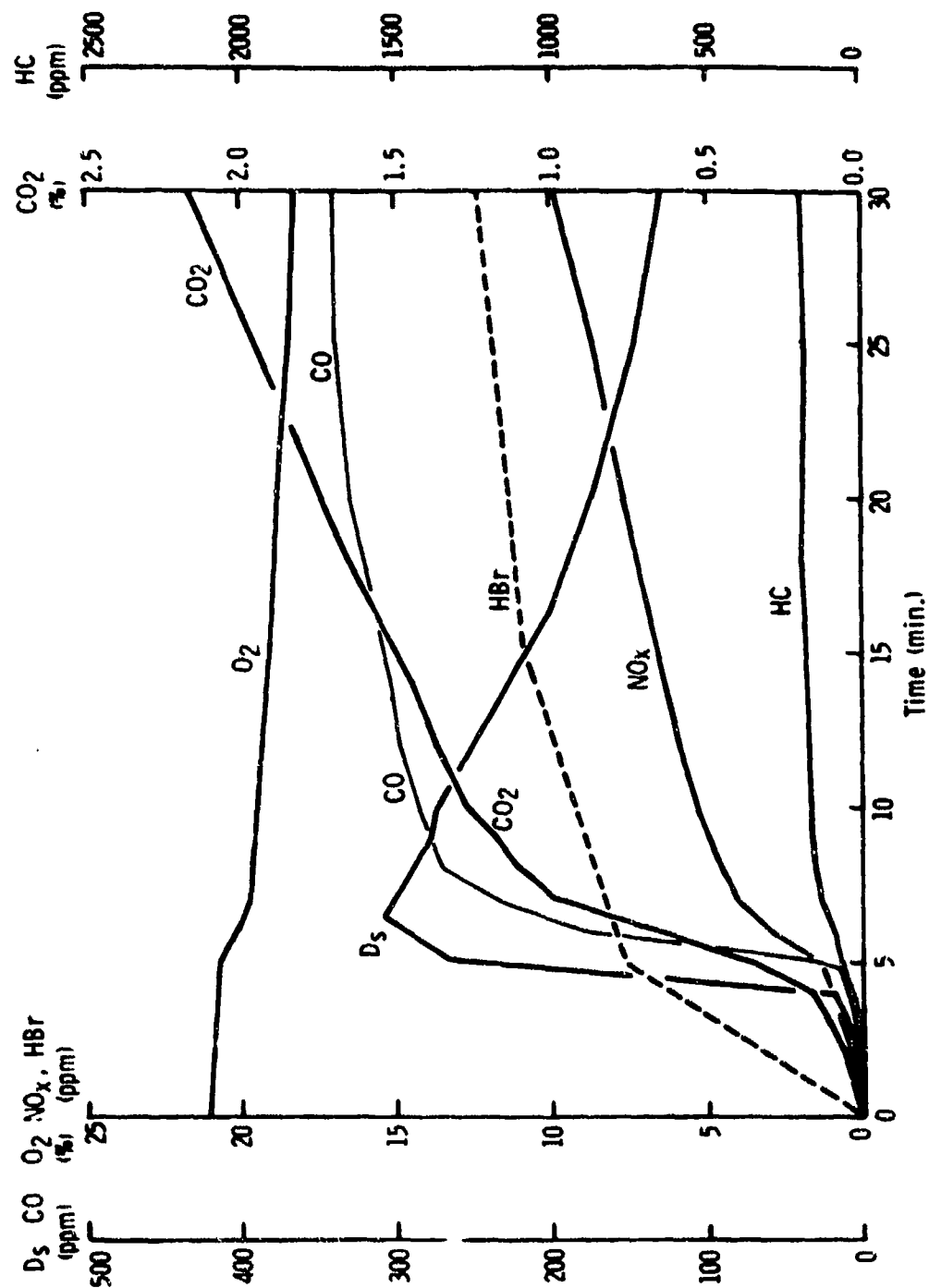
REMARKS

\*Includes CO<sub>2</sub> produced by propane burner flames (~1%).

\*\*NO<sub>x</sub> produced by flames from sample and from burner.

\*\*\*Approximate CO<sub>2</sub> contribution from propane flames has been subtracted.

# Flame Exposure Conditions



# Non-flame Exposure Conditions

## NON-FLAME COMBUSTION PRODUCTS ANALYSIS REPORT

### Sample Description

Sample Number

Material

Sample Composition

Weight (g)

Weight Loss (g)

Weight Loss (%)

Sample Dimensions (cm)

Other

PREPS

3.5788

1.7552

49.0

7.6 x 7.6

(2 pcs - compressed)

Date

Requester

Requesting Organization

MRC Job No.

Worksheet Page No.

Measurement Made by

10-10-75

Sam Sun

MRC

6948

J. Miller

S. Barksdale

Specimen in Bag

Combustion Chamber

Sample Orientation

Imposed Energy Flux (watts/cm<sup>2</sup>)

Flame in Room

Fire Load (kg/m<sup>2</sup>)

Combustion Chamber Temperature (°C)

Initial

Maximum (time)

Final

Application

NBS-Aminco

Horizontal

2.5

No

7 x 10<sup>-3</sup>

50-50

1

NF

Observations During Measurements

Ignition

Flaming

Smoking

Dripping

Intumescence

Other

## MEASUREMENT RESULTS

Data Reported

Single Experiment

Multiple Experiments Under Identical Conditions

Average Values for Multiple Experiments Under Identical Conditions

Average Values for Both Flaming and Nonflaming Test Conditions

Species

$\dot{Q}_{out}$

$\dot{Q}_{out}$  (g/s)

$\dot{Q}_{out}$  (g/s)

Time to  $\dot{Q}_{out}$  (min)

Time to  $\dot{Q}_{out}$  (min)

164

2.08

4.25

Maximum Combustion Products and Minimum Oxygen Concentrations

CO (ppm)

CO<sub>2</sub> (s)

H<sub>2</sub> as methane (ppm)

H<sub>2</sub> (ppm)

H<sub>2</sub> (ppm)

H<sub>2</sub> (ppm)

H<sub>2</sub> (ppm)

O<sub>2</sub> (s)

Other

32

0.02

1925

0.4

14.0

20.9

Time to Attain Maximum Combustion Products and Minimum Oxygen Concentrations (min)

CO

CO<sub>2</sub>

H<sub>2</sub>

H<sub>2</sub>

H<sub>2</sub>

H<sub>2</sub>

O<sub>2</sub>

Other

30

30

30

30

30

30

30

Weight-Based Combustion Products Data - Maximum values with reference to Sample Weight (g/g)

CO

CO<sub>2</sub>

H<sub>2</sub> as methane

H<sub>2</sub>

H<sub>2</sub>

H<sub>2</sub>

H<sub>2</sub>

Other

4.7

4.4

1609

0.06

5.9

21 x (At) Values for 30-Minute Exposure

CO (ppm-min)

CO<sub>2</sub> (s-min)

H<sub>2</sub> (ppm-min)

H<sub>2</sub> (ppm-min)

H<sub>2</sub> (ppm-min)

H<sub>2</sub> (ppm-min)

H<sub>2</sub> (ppm-min)

Other

Time to Reach Specific 21 x (At) Values

CO

CO<sub>2</sub>

H<sub>2</sub>

H<sub>2</sub>

H<sub>2</sub>

H<sub>2</sub>

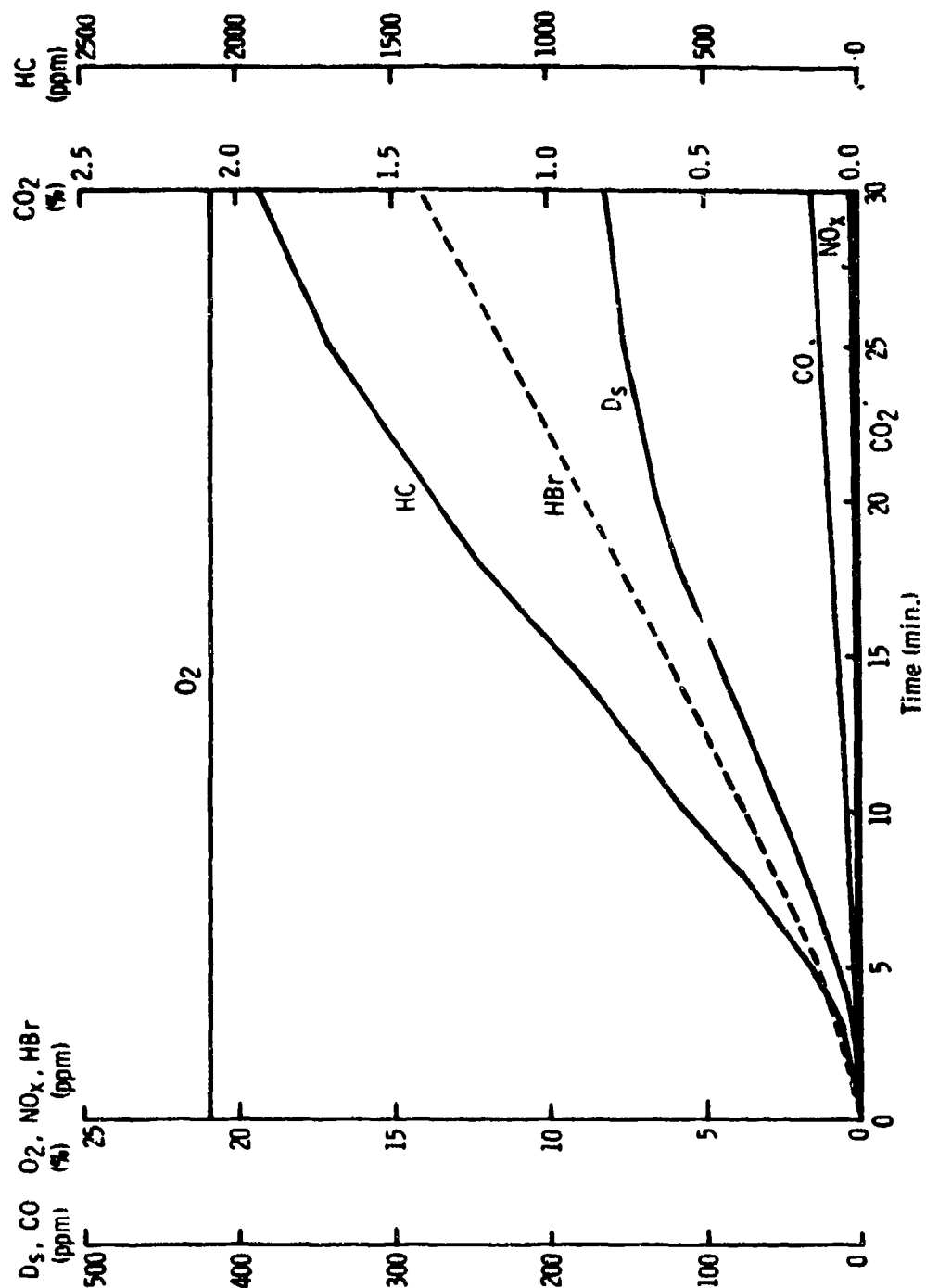
H<sub>2</sub>

Other

0.0001



# Non-flame Exposure Conditions



	<u>Wt (g)</u>
Lustrex HH101	263
Glass microballoons (1G101)	5
Igepal CO-970	17
Methyl chloride	137
Monsanto Co. proprietary fire retardant	5.3
Freon 13B1	34

The charging procedure was the same as that described in section 3.3.3.

One charged cylinder is being stored in our laboratory for 18 months (17 September, 1975 through 16 March, 1977). The other cylinder was discharged on 16 September, 1975. The following data were recorded on the discharge of this cylinder and the properties of the resulting foam:

a. Time to discharge	1 second
b. Appearance of foam	uniform small cell, white-colored
c. Stability of foam	no volume change after discharge
d. Foam density	0.8 lb/cu ft
e. Compressive strength	
at yield	6.51 psi
at 30% compression	5.86 psi
at 60% compression	5.47 psi
f. Percent open cells	83.2
g. Number of cells/inch	30

The percent open cells appears to be abnormally high. It may reflect the effect of the use of the higher pressure Freon 13B1 as a part of the solvent system.

The above data will serve as a basis of comparison for the foam which will be generated after 18 months of storage.

#### 4. CONCLUSIONS

From this work, it can be concluded that polystyrene foam which provides 60 to 61 lb/cu ft of flotation can be generated at a water depth of 15 feet. If the foam is left immersed in water at that depth there is a 20% loss in flotation power in 24 hours. This loss of flotation comes from water being absorbed into the foam. The exact mechanism of water absorption is not known at this time. It may be by water diffusion through intact cell walls, breaking of cell walls by the water pressure, or water entrance into already open cells. However, fine celled foams are definitely more resistant to water pick up than are large celled foams.

Non-burning solvent/pneumatogen systems for the foam solution have been developed. These systems are based on mixtures of methyl chloride and Freon 13B1.

A non-burning polystyrene foam containing only 2% by weight of a flame retardant additive has been developed.

Operation at 14°F (-10°C) is feasible. Operation at temperatures as low as -22°F (-30°C) does not appear feasible using a simple pressure tank. Failure to operate at low temperatures appears to be due to the very high viscosity of the polymer solution at low temperatures. The solution will not flow out of the container under these conditions. If the delivery of foam solution to the outside of the pressure container can be solved, foam formation at temperatures lower than 14°F appears possible.

Up to this time, storage stability does not appear to be a problem with the foam systems developed.

It can be concluded from this work that providing flotation to small vessels in distress using foams is a feasible concept that should be developed further.

## 5. RECOMMENDATIONS FOR FUTURE WORK

It is recommended that this work be continued with particular emphasis on the following areas:

- . Reduction of the water absorption by the foam when immersed under 15 feet of water.
- . Improvement of foam generation at low temperatures, and
- . Development of prototype equipment to be installed and demonstrated in a small vessel.

Specific recommendations in these areas are as follows:

### 5.1 REDUCTION OF WATER ABSORPTION

Work should be done to reduce the amount of water absorption of these foams when they are immersed in 15 feet of water. This work should entail the following:

- . Producing as fine-celled a foam as possible.
- . Toughening of the foam cell walls.
- . Reduction of open cell content to a minimum, and
- . Determining the feasibility of enclosing the foam in a water-impermeable film. This film could be a part of the foam generating equipment and be deployed only at use time.

### 5.2 LOW TEMPERATURE OPERATION

This work should concentrate on the following:

- . Providing the foam solution tanks with a diaphragm which separates the propellant gas (nitrogen), which is necessary at low temperatures, from the foam solution. The diaphragm would furnish a positive means of forcing the highly viscous foam solution from the tank and would prevent gas channeling through the solution.
- . Determining the feasibility of using heaters and/or insulation to maintain the foam solution at more nearly normal temperatures

### 5.3 DEVELOPMENT OF PROTOTYPE EQUIPMENT

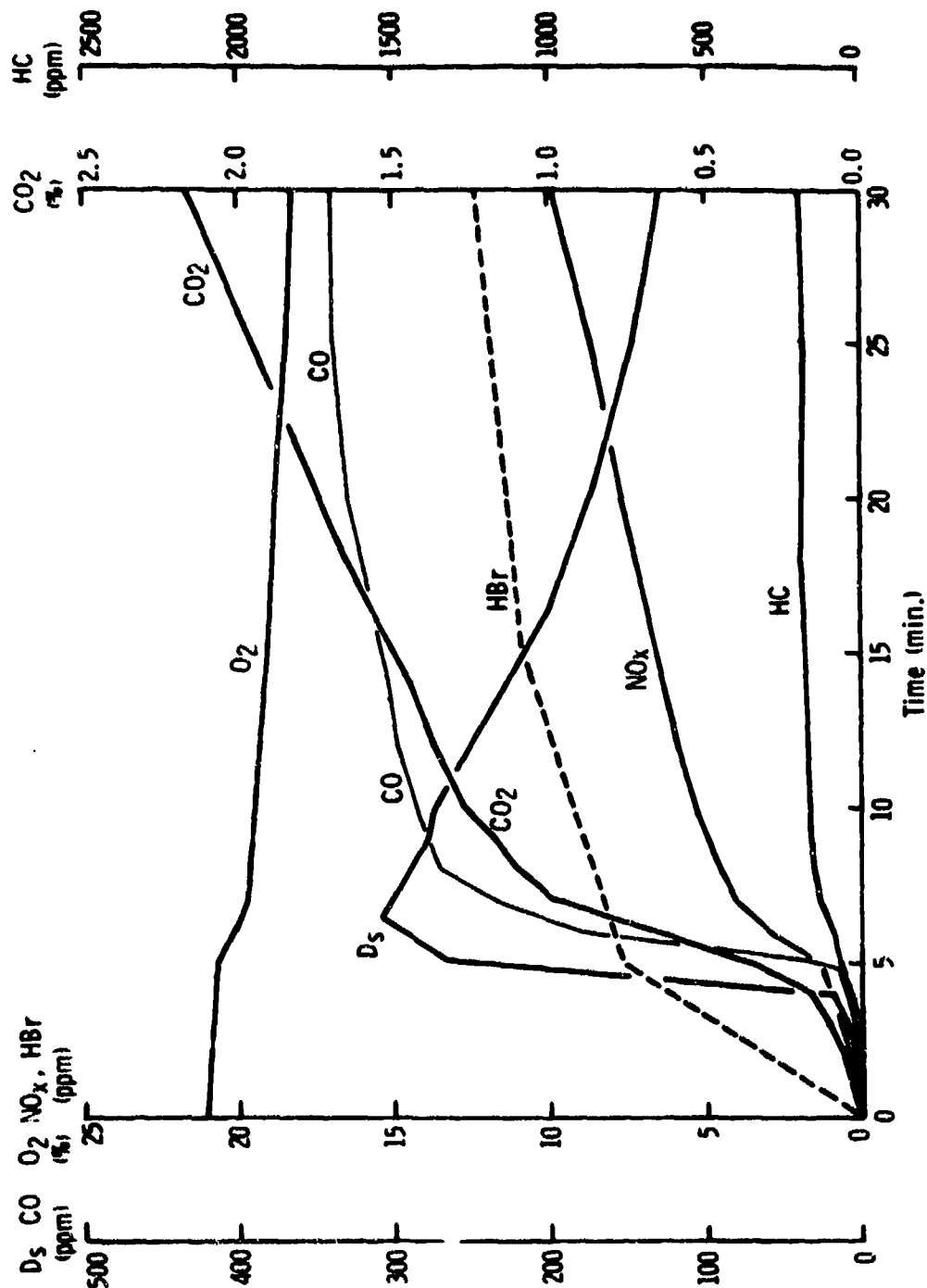
The design and fabrication of an adequate foam system to be installed in a small vessel should be a part of a future program. This would include the design of the necessary tanks, mounting frames and brackets, the actuating means to deploy the foam, and the necessary plumbing and utilities to make the system effective. After design is complete, prototype equipment should be built for demonstration on an actual fishing vessel or other small ship.

APPENDIX

ORIGINAL BURNING DATA AND PLOTS OF COMBUSTION  
PRODUCT CONCENTRATION



Flame Exposure Conditions





# Non-flame Exposure Conditions

## NON-FLAME EXPOSURE CONDITIONS ANALYSIS REPORT

### Specimen Description

Sample Number

Material

Sample Composition

Weight (g)

Weight Loss (g)

Weight Loss (%)

Sample Dimensions (cm)

Other

PREPS

3.5788

1.7552

49.0

7.6 x 7.6

(2 pcs - compressed)

Date

Requester

Requesting Organization

MRC Job No.

Worksheet Page No.

Measurement Made by

10-10-75

Sam Sun

MRC

6948

J. Miller

S. Barksdale

### Specimen Exposure

Combustion Chamber

Sample Orientation

Imposed Energy Flux (MW/m<sup>2</sup>)

Flame in chamber

Fire Load (kg/m<sup>2</sup>)

Combustion Chamber Temperature (°C)

Initial

Maximum (time)

Final

Application

NBS-Aminco

Horizontal

2.5

No

7 x 10<sup>-3</sup>

50-55

1

### Observations During Measurements

Ignition

Flaming

Smoking

Dripping

Intumescence

Other

## MEASUREMENT RESULTS

Data Reported

☒ Single Experiment

☐ Multiple Experiments Under Identical Conditions

☐ Average Values for Multiple Experiments Under Identical Conditions

☐ Average Values for Both Flaming and Nonflaming Test Conditions

Sample

W<sub>0</sub>

W<sub>0</sub> (g)

W<sub>0</sub> (g)

Time to W<sub>0</sub>-16 (min)

Time to W<sub>0</sub> (min)

164

2.08

4.25

Maximum Combustion Products and Minimum Oxygen Concentrations

CO (ppm)

CO<sub>2</sub> (%)

HC as methane (ppm)

H<sub>2</sub> (ppm)

H<sub>2</sub>N (ppm)

H<sub>2</sub>O (ppm)

H<sub>2</sub> (ppm)

O<sub>2</sub> (%)

Other

32

0.02

1925

0.4

14.0

20.9

Time to Attain Maximum Combustion Products and Minimum Oxygen Concentration (min)

CO

CO<sub>2</sub>

HC

H<sub>2</sub>

H<sub>2</sub>N

H<sub>2</sub>O

H<sub>2</sub>

O<sub>2</sub>

Other

Weight-Based Combustion Products Data - Maximum values with reference to sample weight (g/g)

CO

CO<sub>2</sub>

HC as methane

H<sub>2</sub>

H<sub>2</sub>N

H<sub>2</sub>O

H<sub>2</sub>

Other

4.7

4.4

1609

0.06

5.9

ΔL (at) Values for 30-Minute Exposure

CO (ppm-min)

CO<sub>2</sub> (g-min)

HC (ppm-min)

H<sub>2</sub> (ppm-min)

H<sub>2</sub>N (ppm-min)

H<sub>2</sub>O (ppm-min)

H<sub>2</sub> (ppm-min)

Other

Time to Reach Specified ΔL (at) Values

CO

CO<sub>2</sub>

HC

H<sub>2</sub>

H<sub>2</sub>N

H<sub>2</sub>O

H<sub>2</sub>

Other

REMARKS

# Non-flame Exposure Conditions

